case constituent for lateral model transport due to its greatest concentration reduction factor.

7.5.3 Results for Vertical Waste Transport Through Rock

By combining the vertical transport components at Ineos, the total vertical transport of the waste constituent acrylamide in the overlying containment interval (from the top of the WDW-163 Injection Interval), to a 4,000,000,000-fold reduction in concentration, is determined:

$$Z_{total} = Z_{advection} + Z_{diffusion}$$

$$= 0.83 \text{ feet} + 142 \text{ feet} = 143 \text{ feet}$$

Using the defined vertical model Injection Interval top at WDW-163 (proposed top at 5,370 feet KB; higher than the current Injection Interval top of 5,422 feet KB) as the beginning point for vertical waste transport (to a 4×10^9 reduction) results in a waste front migration upward over 10,000 years to a depth of 5,227 feet KB (5,370 ft – 143 ft). The thickness of the containment interval above a depth of 5,370 feet is 645 feet at WDW-163, as discussed in Section 4.0, with the top of the Injection Zone at 4,725 feet at WDW-163. Thus, the 10,000-year total vertical transport by the injected waste is contained within the upper containment interval, and remains below the top of the Injection Zone.

The calculated vertical waste transport distance is conservative since the maximum Injection Interval pressure buildup was applied to the Injection Interval during the entire historical and projected operational periods, a conservatively high containment interval permeability was assigned, and the worst-case concentration reduction factor was used. The result is an over-estimated waste transport distance during the operational and 10,000-year post-operational periods.

As noted above, Table 7-9 includes a column listing the vertical diffusion distance through rock for all of the petitioned constituents. None of the constituents have

sufficient combined diffusive and advective movement capable of reaching to the top of the Injection Zone, and so all constituents meet the vertical model demonstration that they remain within the Injection Zone over a period of 10,000 years.

7.5.4 Molecular Diffusion Through Mud-Filled Boreholes

The modeling results discussed above address the issue of waste movement through a porous medium. This section assesses the extent of vertical diffusion over 10,000 years through a worst-case mud-filled abandoned borehole that could penetrate the Injection Interval and intersect the location of a modeled 10,000-year plume.

The calculation is conservative because it assumes that full strength waste would be at the location of a mud-filled borehole for 10,000 years, when in reality lateral plume movement and dispersivity substantially reduce the plume concentrations over 10,000 years. The following calculations also employ a mud tortuosity of 0.5, which conservatively reflects the plated nature of the clay particles in the mud column (as discussed in Section 7.3.5). Thus a maximum vertical diffusion distance is calculated for the given molecular diffusivity.

The vertical extent of molecular diffusion for a dissolved constituent through a mud-filled borehole is calculated from the solution (Crank, 1975) to Fick's second law, as presented earlier in Equation (7.12):

$$c/c_o = 1\text{-}erf[z/2\{D^* t\}^{1/2}] \qquad (7.12)$$

Using the parameters specified previously for Equation (7.12) with a revised tortuosity of 0.5 for a mud-filled borehole:

$$\begin{aligned} c/c_o &= 4 \times 10^{-9} \\ D^* &= 7.96 \times 10^{-4}\ ft^2/day \times 0.50 \\ &= 3.98 \times 10^{-4}\ ft^2/day \\ t &= 10{,}000\ years \times 365.25\ day/yr \\ &= 3.6525 \times 10^{6}\ days \end{aligned}$$

The vertical diffusion distance, to a 4 x 10^9 reduction in concentration, through a mud-filled borehole was calculated using Equation 7.12:

$$4 \times 10^{-9} = 1\text{-erf}[z/2\{(3.98 \times 10^{-4}\ ft^2/day)(3.6525 \times 10^6\ days)\}^{1/2}])$$

$$z / 2(D^*t)^{1/2} = 4.16$$

$$z = (2)(4.16)[(3.98 \times 10^{-4}\ ft^2/day)(3,652,500\ days)]^{1/2}$$

solving for z ($z_{borehole}$):

$$z_{borehole} = 317 \text{ feet}$$

This value is included in Table 7-9, which also shows the calculated vertical diffusion distances for all of the petitioned constituents through a mud-filled borehole. From this table it is evident that some constituents with greater molecular diffusivities (and smaller CRFs) have more vertical movement due to diffusive transport. However, none of these constituents have sufficient diffusive movement capable of reaching to the top of the Injection Zone, and so all constituents meet the vertical model demonstration that they remain within the Injection Zone over a period of 10,000 years.

7.6 Model Conclusions

This modeling effort provides a demonstration of "no migration" in accordance with 40 CFR §148.20(a)(8) regulations. This has been accomplished by demonstrating that Ineos' injected wastewater constituents will not migrate out of the Injection Zone at hazardous levels and will be contained both vertically and laterally within the Injection Zone for a period of at least 10,000 years.

The modeling accounts for Injection Interval pressurization during the operational period, and the post-operational 10,000-year lateral and vertical waste transport. Conservative models have been constructed and used to determine the maximum pressure buildup, and lateral and vertical waste transport distances. The modeling results demonstrate that no harm or impairment to the environment will occur from continued injection operations at the Ineos facility, through either endangerment (Injection Interval pressurization), lateral

waste transport (updip or downdip), or vertical waste transport. The modeling results are summarized in Tables 7-6a, 7-7a and 7-8a (WDW-163 Injection Interval), Tables 7-6b, 7-7b, and 7-8b (WDW-164 Injection Interval), and Tables 7-6c, 7-7c, and 7-8c (WDW-165/Well No. 4 Injection Interval).

SWIFT models were developed and run to determine the Injection Interval pressure buildup for a projected operational period of 10 years, and to predict the location of the boundaries of the injected plumes after 10,000-years (light plumes) and 200 years (heavy plumes). For the WDW-163 Injection Interval, lateral (low density and high density) plume migration is depicted on Figures 7-16 and 7-19; updip plume migration is also shown on Plate 3-1. For the WDW-164 Injection Interval, lateral (low density and high density) plume migration is depicted on Figures 7-17 and 7-20; updip plume migration is also shown on Plate 3-1. For the WDW-165 Injection Interval, lateral (low density and high density) plume migration is depicted on Figures 7-18 and 7-21; updip plume migration is also shown on Plate 3-1.

The WDW-163 model results indicate that, for a 4×10^9 order of magnitude reduction in the initial concentration, the boundaries of the low density injectate plume in 10,000 years will be approximately 18,500 feet upgradient, and 7,000 feet downgradient from the WDW-163 injection well. The plume is approximately 34,000 feet wide at the widest point. The high density plume boundaries extend approximately 5,500 feet updip and 6,000 feet downdip of the WDW-163 injection well after 200 years post-operations.

The WDW-164 model results indicate that, for a 4×10^9 order of magnitude reduction in the initial concentration, the boundaries of the low density injectate plume in 10,000 years will be approximately 15,500 feet upgradient, and 5,500 feet downgradient from the WDW-164 injection well. The plume is approximately 12,000 feet wide at the widest point. The high density plume boundaries extend approximately 4,000 feet updip and 4,500 feet downdip of the WDW-164 injection well after 200 years post-operations.

The WDW-165 model results indicate that, for a 4 x 10^9 order of magnitude reduction in the initial concentration, the boundaries of the low density injectate plume in 10,000 years will be approximately 11,500 feet upgradient, and 5,000 feet downgradient from the WDW-165 injection well. The plume is approximately 10,000 feet wide at the widest point. The high density plume boundaries extend approximately 3,500 feet updip and 4,000 feet downdip of the WDW-165 injection well after 200 years post-operations.

The maximum pressure buildups at the Ineos wells of 253 psi (WDW-163), 767 psi (WDW-164), and 615 psi (WDW-165) occur at the end of 10 years of future injection at maximum the permitted injection rates of 500 gpm per well. Injection Interval pressure buildup isopleths are depicted on Figures 3-1, 3-2, and 3-3. The initial bottom-hole pressure (BHP) at the node center of the WDW-163 well location (node x = 72, y = 68) is 2,207 psi at the end of the 10,000-day stabilization period. This value was obtained from the pressures at elevation output in the SWIFT output file 163pr34. The final flowing BHP is 2,460 psi at the end of injection. This value was obtained from the well summary table at the end of injection in the same output file. The difference (2,460 – 2,207 psi) is 253 psi. The calculated cone of influence for the WDW-163 Injection Interval, 365 psi, does not extend past the well. The initial bottom-hole pressure (BHP) at the node center of the WDW-164 well location (node x = 48, y = 32) is 3,243 psi at the end of the 10,000-day stabilization period. This value was obtained from the pressures at elevation output in the SWIFT output file 164pr42. The final flowing BHP is 4,010 psi at the end of injection. This value was obtained from the well summary table at the end of injection in the same output file. The difference (4,010 – 3,243 psi) is 767 psi. The calculated cone of influence for the WDW-164 Injection Interval, 392 psi, is within 50 feet of the well. The initial bottom-hole pressure (BHP) at the node center of the WDW-165 well location (node x = 48, y = 32) is 2,995 psi at the end of the 10,000-day stabilization period. This value was obtained from the pressures at elevation output in the SWIFT output file 165pr52. The final flowing BHP is 3,610 psi at the end of injection. This value was obtained from the well summary table at the end of injection in the same output file. The

difference (3,610 – 2,995 psi) is 615 psi. The calculated cone of influence for the WDW-165 Injection Interval, 375 psi, is within 200 feet of the well.

A conservative analytical model was used to determine the vertical advective transport resulting from the pressure buildup during the historical and projected operational periods. The results indicate that the vertical advective transport during the operational periods would be 0.83 feet above the top of the shallowest (WDW-163) Injection Interval. In addition, 142 feet of vertical migration was calculated by the 10,000-year molecular diffusion analytical model for acrylamide, for a total modeled predicted vertical migration in 10,000 years of 143 feet above the shallowest (WDW-163) Injection Interval. In conclusion, the modeling results demonstrate that no harm or impairment to the environment will occur from continued injection operations at the Ineos facility, through either endangerment (increased operating pressure), lateral migration, or vertical migration of injected wastewaters.

REFERENCES

Adams, E.E., and L.W. Gelhar, 1992, "Field Study of Dispersion in a Heterogeneous Aquifer: 2. Spatial Moments Analysis", Water Resources Research, Vol. 28, No. 12, pp. 3293-3307.

Anderson, M.P., 1984, "Movement of Contaminants in Groundwater: Groundwater Transport-Avection and Dispersion", Groundwater Contamination, National Academy Press, Washington, D.C., pp. 37-45.

Carslaw, H.S., and J.C. Jaeger, 1959, Conduction of heat in Solids, Oxford University Press, Oxford England, 2nd Edition, 510 p.

Clark, D. A., 1988, "An Experimental Evaluation of Containment Properties for Shales Associated with Deep-Well Hazardous Waste Injection Zones", M. S. Thesis, Louisiana State University, Baton Rouge, LA.

Conger, R. M., 1986, "Upper Miocene Injection Reservoir of the Geismar – St. Gabrial Area, Iberville and Ascension Parishes, Louisiana", Journal of Underground Injection Practices, pp. 239-257.

TERRA DYNAMICS INC

CRC Handbook of Chemistry and Physics, 1979, Lide, D. R., editor, CRC Press, Boston, 58th Edition.

Daniel, D. E., and C. D. Shackelford, 1988, "Disposal Barriers that Release Contaminants Only by Molecular Diffusion", Nuclear and Chemical Waste Management, Vol. 8, pp. 299-305.

Davis, S.N., D.J. Campbell, H.W. Bentley, and T.J. Flynn, 1985, Ground-Water Tracers, National Water Well Assn. and U.S. EPA Robert S. Kerr Environmental Research Laboratory, U.S. EPA and University of Arizona cooperative agreement CR-81003601-0, 200 p.

DHHS, U. S. Department of Health and Human Services—NIOSH, 1990, Pocket Guide to Chemical Hazards, Publication 90-117, Washington D. C., 245 pp.

Domenico, P. A., and F. W. Schwartz, 1990, Physical and Chemical Hydrogeology, J. Wiley and Sons, New York, 824 p.

Earlougher, R.C., 1977, "Advances in Well Test Analysis", H.L. Doherty Series, Monograph Vol. 5, Society of Petroleum Engineers of AIME, 264 p.

Finley, N.C., and M. Reeves, 1982, "SWIFT Self-Teaching Curriculum", NUREG/CR-1968, SAND81-0410, Sandia National Laboratories, Albuquerque, NM, 169 p.

Freeze, A.R., and J.A. Cherry, 1979, Groundwater, Prentice-Hall, Inc., Englewood Cliffs, N.J., 604 p.

Gelhar, L.W., A.L. Gutjahr, and R.L. Naff, 1979, "Stochastic Analysis of Macrodispersion in a Stratified Aquifer", Water Resources Research, Vol. 15, pp. 1387-1397.

Gelhar, L. W., C. Welty, and K. R. Rehfeldt, 1992, A Critical Review of Data on Field-Scale Dispersion in Aquifers, Water Resources Research, v. 28, pp. 1955-1974.

Hewlett Packard, 1982, HP41C Petroleum Fluids Pac Manual, Hewlett Packard Corporation, Fort Collins, Colorado, 199 p.

HSI Geotrans, 2000, Swift for Windows Sandia Waste Isolation Flow and Transport Model, 45060 Manekin Pl, Suite 100 C, Sterling, VA 20166.

Intercomp Resources Development and Engineering, Inc., 1976, "Development of Model for Calculating Disposal in Deep Saline Aquifers, Parts I and II", USGS/WRI 76-61, National Technical Information Service, Washington, D.C., 236 p.

Intera, 1994, "Reissuance of Deepwell No-Migration Petition Exemption for BP Chemicals, Inc. Green Lake Complex, Port Lavaca, Texas", Company Report Submitted to USEPA, Dallas, Texas.

Johnson, R. L., J. A. Cherry, and J. F. Pankow, 1989, "Diffusive Contaminant Transport in Natural Clay: A field Example and Implications for Clay-Lined Waste Disposal Sites,: Environmental Science and Technology, Vol. 23, pp. 340-349.

Lerman, A., 1988, Geochemical Processes Water and Sediment Environments, John Wiley and Sons, New York, N.Y., 481 pp.

MacKay, D.M., P.V. Roberts, and J.A. Cherry, 1985, "Transport of Organic Contaminants in Groundwater", Environmental Science and Technology, Vol. 19, No. 5, pp. 384-392.

Magara, K. , 1969, "Porosity-Permeability Relationship of Shale," Society of Petroleum Engineers Paper No. 2430.

Magcobar, 1980, Drilling Fluid Engineering Manual, Magcobar Division Oilfield Products Group, Dresser Industries, Inc., Houston, TX.

Miller, C., 1989, Modeling Molecular Diffusion in No Migration Demonstration, Proceedings of the International Symposium on Class I and II Injection Well Technology, UIPC Research Foundation, Dallas, Texas, pp 281-316.

Numbere, D., W. E. Brigham, and M. B. Standing, 1977, Correlations for Physical Properties of Petroleum Reservoir Brines, Petroleum Research Institute, Stanford University, November, 1977, p. 16.

Pearce, M., 1989, Long-Term Properties of Clay, Water-Based Drilling Fluids, Proceedings of the International Symposium on Class I and II Injection Well Technology, UIPC Research Foundation, Dallas, Texas, pp 115-131.

Perry, R.H., 1997, Perry's Chemical Engineers' Handbook, Seventh Edition, McGraw-Hill Book Company, New York, N.Y.

Reeves, M.D., and D.S. Ward, 1986, "SWIFT II Self-Teaching Curriculum", NUREG/CR-3925, Sandia National Laboratories, Albuquerque, NM, 105 p.

Reeves, M.D., D.S. Ward, N.D. Johns, and R.M. Cranwell, 1986, "Theory and Implementation for SWIFT II, the Sandia Waste-Isolation Flow and Transport Model for Fractured Media, Release 4.84", NUREG/CR-3328 or SAND83-1159, Sandia National Laboratories, Albuquerque, NM, 189 p.

Reeves, M.D., D.S. Ward, P.A. Davis, and E.J. Bonano, 1987, "SWIFT II Self-Teaching Curriculum: Illustrative Problems for the Sandia Waste-Isolation Flow and Transport Model for Fractured Media", NUREG/CR-3925 or SAND84-1586, Sandia National Laboratories, Albuquerque, NM, 94 p.

Ward, D.S., M. Reeves, and L.E. Duda, 1984, "Verification and Field Comparison of the Sandia Waste-Isolation Flow and Transport Model (SWIFT)", NUREG/CR-3316 or SAND83-1154, Sandia National Laboratories, Albuquerque, NM.

Ward, D.S., D.R. Buss, J.W. Mercer, and S.S. Hughes, 1987, "Evaluation of a Groundwater Corrective Action at the Chem-Dyne Hazardous Waste Site Using a Telescopic Mesh Refinement Modeling Approach", Water Resources Research, Vol. 23, No. 4, pp. 603-617.

Xu, M. and Y Eckstein, 1995, Use of Weighted Least-Squares Method in Evaluation of the Relationship Betrween Dispersivity and Field Scale, Ground Water, v. 33, pp 905-908.

TABLE 7-1

SUMMARY OF MODELING APPROACH

General Model Description	*General Modeling Approach*
Lateral Injection Interval Pressurization	2-D Numerical Model (SWIFT)
Lateral Plume Transport for High Density Injectate	2-D Numerical Model (SWIFT)
Lateral Plume Transport for Low Density Injectate	2-D Numerical Model (SWIFT)
Vertical Transport of Injectate	1-D Analytical Model

MAY - 6 2009

TABLE 7-2a

SWIFT Model Input Parameters
WDW-163 Injection Interval

Ineos USA LLC
Port Lavaca, Texas

Parameter	Value	Units	Comments
Thickness of Injection Interval	Variable based on geologic mapping	feet	Derived from geologic isopach maps.
Permeability of Injection Interval	1,600 (163lo32 and 163hi33) 500 (163pr34)	millidarcy	Derived from worst case values which bracket historical WDW-163 fall-off tests.
Hydraulic Conductivity of Injection Interval used in SWIFT Model	9.68 (163lo32 and 163hi33) 3.02 (163pr34)	feet/day	Derived from worst case permeability values from available well test data.
Vertical Hydraulic Conductivity of Containment Interval Overlying Injection Interval used inVertical Model	4.12×10^{-6}	feet/day	Derived from BP Whole core analyses. Based on weighted average of vertical permeabilities of core from shale and sandstone in Containment Interval.
Porosity of Injection Interval	0.34	fractional	Derived from Whole Core Analyses and porosity logs. Based on average of porosities in Injection Interval.
Porosity of Containment Interval	0.10 (shale) 0.28 (sand)	fractional	Derived from Whole Core Analyses and Gulf Coast references.
Effective Molecular Diffusivity used in SWIFT lateral models	9.2×10^{-5}	$feet^2$ / day	Johnson and others (1989) using properties for acrylamide.
Effective Molecular Diffusivity used in analytical vertical model	7.96×10^{-5}	$feet^2$ / day	Johnson and others (1989) using properties for acrylamide.
Free Water Molecular Diffusivity	7.96×10^{-4}	$feet^2$ / day	Johnson and others (1989) using properties for acrylamide.
Tortuosity – vertical Tortuosity -- lateral	0.10 0.34	fractional	Vertical Model through sand & shale Lateral Model through sand only.

TABLE 7-2a (cont.)

SWIFT Model Input Parameters
WDW-163 Injection Interval

Parameter	Value	Units	Comments
Formation Brine Specific Weight (Density)	64.89 at 158 °F	lb / ft^3	Brine Analysis from WDW-163. 86,700 mg/l NaCl (8.2% NaCl)
Injection Fluid Specific Weight (Density)	62.18 at 158 °F (163lo32) 65.30 at 158 °F(163hi33,163pr34)	lb / ft^3 lb / ft^3	1.02 sp. gr. NH_4SO_4 at 158 °F 1.07 sp. gr. NH_4SO_4
Initial Bottom Hole Pressure	2,190 @ 5,464 feet	psia	Corrected From WDW-163 Initial bottom-hole pressure measurement.
Formation Fluid Viscosity	0.47 at 158 °F	centipoise	Determined From Earlougher (1977) Figure D.35
Injection Fluid Viscosity	0.42 at 158 °F (163lo32) 0.49 at 158 °F (163hi33, 163pr34)	centipoise centipoise	Determined From Earlougher (1977) Figure D.35.
Compressibility of Formation Brine	2.56×10^{-6}	psi^{-1}	Determined from Hewlett Packard (1982).
Compressibility of Formation Matrix	3.0×10^{-6}	psi^{-1}	Determined From Earlougher (1977) Figure D.12.
Formation Temperature	158	°Fahrenheit	Measured from WDW-163 temperature log.
Longitudinal Dispersivity	160	feet (ft)	Gelhar and others (1992)
Transverse Dispersivity	16	feet (ft)	Gelhar and others (1992)
Regional Dip	variable	degrees	From structure map on top of Injection Interval
Skin Factor	0.0	[-]	No skin modeled. Conservative because all pressure increase in the model is due to injection.
Regional Darcy Velocity	0.0	ft/day	No regional flow included to maximize updip plume movement.

TABLE 7-2b

SWIFT Model Input Parameters
WDW-164 Injection Interval

Ineos USA LLC
Port Lavaca, Texas

Parameter	Value	Units	Comments
Thickness of Injection Interval	Variable based on geologic mapping	feet	Derived from geologic isopach maps.
Permeability of Injection Interval	400 (164lo40 and 164hi41) 40 (164pr42)	millidarcy	Derived from worst case values which bracket historical WDW-164 fall-off tests.
Hydraulic Conductivity of Injection Interval used in SWIFT Model	2.82 (164lo40 and 164hi41) 0.28 (164pr42)	feet/day	Derived from worst case permeability values from available well test data.
Vertical Hydraulic Conductivity of Containment Interval Overlying Injection Interval used inVertical Model	7.76×10^{-6}	feet/day	Derived from BP Whole Core analyses. Based on weighted average of vertical permeabilities of core from shale and sandstone in Containment Interval.
Porosity of Injection Interval	0.30	fractional	Derived from Whole Core Analyses and porosity logs. Based on average of porosities in Injection Interval.
Porosity of Containment Interval	0.10 (shale) 0.28 (sand)	fractional	Derived from Whole Core Analyses and Gulf Coast references.
Effective Molecular Diffusivity used in SWIFT lateral models	7.16×10^{-5}	$feet^2$ / day	Johnson and others (1989) using properties for acrylamide.
Effective Molecular Diffusivity used in analytical vertical model	7.96×10^{-5}	$feet^2$ / day	Johnson and others (1989) using properties for acrylamide.
Free Water Molecular Diffusivity	7.96×10^{-4}	$feet^2$ / day	Johnson and others (1989) using properties for acrylamide.
Tortuosity – vertical Tortuosity -- lateral	0.10 0.30	fractional	Vertical Model through sand & shale, Lateral Model through sand only.

TABLE 7-2b (cont.)

SWIFT Model Input Parameters
WDW-164 Injection Interval

Parameter	Value	Units	Comments
Formation Brine Specific Weight (Density)	64.34 at 192 °F	lb / ft^3	Brine Analysis from WDW-163. 86,700 mg/L NaCl (8.2% NaCl)
Injection Fluid Specific Weight (Density)	61.50 at 192 °F (164lo40) 64.62 at 192 °F (164hi41, 164pr42)	lb / ft^3 lb / ft^3	1.02 sp. gr. NH_4SO_4 at 192 °F 1.07 sp. gr. NH_4SO_4
Initial Bottom Hole Pressure	3,175 @ 7,614 feet	psia	Corrected From WDW-164 Initial bottom-hole pressure measurement.
Formation Fluid Viscosity	0.40 at 192 °F	centipoise	Determined From Earlougher (1977) Figure D.35.
Injection Fluid Viscosity	0.34 at 192 °F (164lo40) 0.42 at 192 °F (164hi41, 164pr42)	centipoise centipoise	Determined From Earlougher (1977) Figure D.35.
Compressibility of Formation Brine	2.59×10^{-6}	psi^{-1}	Determined from Hewlett Packard (1982).
Compressibility of Formation Matrix	3.0×10^{-6}	psi^{-1}	Determined From Earlougher (1977) Figure D.12.
Formation Temperature	192	°Fahrenheit	Corrected from WDW-163 temperature log
Longitudinal Dispersivity	160	feet (ft)	Gelhar and others (1992)
Transverse Dispersivity	16	feet (ft)	Gelhar and others (1992)
Regional Dip	variable	degrees	From structure map on top of Injection Interval
Skin Factor	0.0	[-]	No skin modeled. Conservative because all pressure increase in the model is due to injection.
Regional Darcy Velocity	0.0	ft/day	No regional flow included to maximize updip plume movement.

TABLE 7-2c

SWIFT Model Input Parameters
WDW-165 Injection Interval

Ineos USA LLC
Port Lavaca, Texas

Parameter	Value	Units	Comments
Thickness of Injection Interval	Variable based on geologic mapping	feet	Derived from geologic isopach maps.
Permeability of Injection Interval	147 (165lo50 and 165hi51) 33 (165pr52)	millidarcy	Derived from worst case values which bracket historical WDW-165 fall-off tests.
Hydraulic Conductivity of Injection Interval used in SWIFT Model	0.99 (165lo50 and 165hi51) 0.22 (165pr52)	feet/day	Derived from worst case permeability values from available well test data.
Vertical Hydraulic Conductivity of Containment Interval Overlying Injection Interval used inVertical Model	6.33×10^{-6}	feet/day	Derived from BP Whole Core analyses. Based on weighted average of vertical permeabilities of core from shale and sandstone in Containment Interval.
Porosity of Injection Interval	0.28	fractional	Derived from Whole Core Analyses and porosity logs. Based on average of porosities in Injection Interval.
Porosity of Containment Interval	0.10 (shale) 0.28 (sand)	fractional	Derived from Whole Core Analyses and Gulf Coast references.
Effective Molecular Diffusivity used in SWIFT lateral models	6.24×10^{-5}	$feet^2$ / day	Johnson and others (1989) using properties for acrylamide.
Effective Molecular Diffusivity used in analytical vertical model	7.96×10^{-5}	$feet^2$ / day	Johnson and others (1989) using properties for acrylamide.
Free Water Molecular Diffusivity	7.96×10^{-4}	$feet^2$ / day	Johnson and others (1989) using properties for acrylamide.
Tortuosity – vertical Tortuosity -- lateral	0.10 0.28	fractional	Vertical Model through sand & shale. Lateral Model through sand only.

TABLE 7-2c (cont.)

SWIFT Model Input Parameters
WDW-165 Injection Interval

Parameter	Value	Units	Comments
Formation Brine Specific Weight (Density)	64.51 at 182 °F	lb / ft^3	Brine Analysis from WDW-163. 86,700 mg/L NaCl (8.2% NaCl)
Injection Fluid Specific Weight (Density)	61.75 at 182 °F (165lo50) 64.86 at 182 °F (165hi51, 165pr52)	lb / ft^3 lb / ft^3	1.02 sp. gr. NH_4SO_4 at 182°F 1.07 sp. gr. NH_4SO_4
Initial Bottom Hole Pressure	2,881 @ 6,960 feet	psia	Corrected From WDW-164 Initial bottom-hole pressure measurement.
Formation Fluid Viscosity	0.42 at 182 °F	centipoise	Determined From Earlougher (1977) Figure D.35.
Injection Fluid Viscosity	0.37 at 182 °F (165lo50) 0.44 at 182 °F (165hi51, 165pr52)	centipoise centipoise	Determined From Earlougher (1977) Figure D.35.
Compressibility of Formation Brine	2.57×10^{-6}	psi^{-1}	Determined from Hewlett Packard (1982).
Compressibility of Formation Matrix	3.0×10^{-6}	psi^{-1}	Determined From Earlougher (1977) Figure D.12.
Formation Temperature	182	°Fahrenheit	Corrected from WDW-163 temperature log.
Longitudinal Dispersivity	160	feet (ft)	Gelhar and others (1992)
Transverse Dispersivity	16	feet (ft)	Gelhar and others (1992)
Regional Dip	variable	degrees	From structure map on top of Injection Interval
Skin Factor	0.0	[-]	No skin modeled. Conservative because all pressure increase in the model is due to injection.
Regional Darcy Velocity	0.0	ft/day	No regional flow included to maximize updip plume movement.

TABLE 7-3

Ineos Historical Fall-Off Testing Results WDW-163, WDW-164, WDW-165

WDW-163

Date of Test	Transmissibility (mD-ft/cP)	Permeability (mD)	Skin Factor	Viscosity (cP)	Thickness (feet)	Injection Rate (gpm)	Fall-off Period (hr)
April 1989	250,971	576	+709	0.56	244	--	--
April 1990	243,129	558	+497	0.56	244	--	--
Jan 1991	252,279	579	0	0.56	244	--	--
March 1992	235,286	540	+24	0.56	244	--	--
March 1993	271,886	624	+93	0.56	244	100	12
March 1994	259,686	596	+151	0.56	244	100	10
March 1995	289,600	617	+253	0.52	244	100	11
March 1996	291,600	621	+153	0.52	244	150	8
March 1997	290,883	620	+99	0.52	244	125	13
April 1998	301,661	643	+78	0.52	244	150	17
April 1999	594,246	1,266	+500	0.52	244	92	14
April 2000	751,378	1,600	+488	0.52	244	130	19
March 2001	473,196	1,008	+355	0.52	244	160	24
March 2002	537,394	1,145	+350	0.52	244	160	16
March 2003	538,652	1,122	+375	0.52	244	150	18
March 2004	594,461	1,267	+384	0.52	244	150	17
March 2005	554,315	1,181	+363	0.52	244	150	15
April 2006	786,634	1,676	+619	0.52	244	150	21
May 2007	234,232	500	+128	0.52	244	110	19
April 2008	277,053	590	+159	0.52	244	142	20
April 2009	1,108,334	2,348	+1,291	0.52	244	90	19
April 2010	552,370	1,177	+276	0.52	244	150	21
April 2011	19,078	41	+6	0.52	244	105	21
July 2012	585,916	1,249	+477	0.52	244	110	21
April 2013	485,308	1,034	+360	0.52	244	150	21
May 2014	366,297	781	+189	0.52	244	125	21
July 2015	470,537	1,003	+357	0.52	244	70	25

TABLE [illegible] (continued)

Ineos Historical Fall-Off Testing Results WDW-163, WDW-164, WDW-165

WDW-164

Date of Test	Transmissibility (mD-ft/cP)	Permeability (mD)	Skin Factor	Viscosity (cP)	Thickness (feet)	Injection Rate (gpm)	Fall-off Period (hr)
Oct 1985	33,223	62	+27	0.56	305	--	--
Oct 1986	31,589	58	+40	0.56	305	--	--
Oct 1987	44,661	82	+47	0.56	305	--	--
March 1988	43,571	80	+45	0.56	305	--	--
Feb 1989	64,813	119	+175	0.56	305	--	--
April 1990	29,411	54	+48	0.56	305	--	--
May 1991	66,446	122	+76	0.56	305	--	--
March 1992	72,982	134	+91	0.56	305	--	--
March 1993	58,277	107	+70	0.56	305	100	14
March 1994	58,294	96	+30	0.56	305	100	12
March 1995	60,140	89	+41	0.45	305	100	11
March 1996	94,080	139	+46	0.45	305	250	11
March 1997	115,387	170	+70	0.45	305	250	12
April 1998	116,400	172	+79	0.45	305	220	13
April 1999	97,669	144	+126	0.45	305	165	16
April 2000	183,134	270	+107	0.45	305	190	15
March 2001	186,783	276	+134	0.45	305	245	17
March 2002	254,347	375	+155	0.45	305	290	12
March 2003	228,948	338	+205	0.45	305	190	16
March 2004	135,202	199	+154	0.45	305	135	12
March 2005	94,014	140	+110	0.45	305	150	13
April 2006	138,224	213	+85	0.45	305	200	14
May 2007	122,943	181	+28	0.45	305	300	21
April 2008	115,459	170	+37	0.45	305	210	14
April 2009	128,427	189	+50	0.45	305	280	12
March 2010	115,427	170	+39	0.45	305	200	15
April 2011	116,356	172	+37	0.45	305	300	13
July 2012	140,250	207	+43	0.45	305	370	14
May 2013	126,867	187	+60	0.45	305	250	14
May 2014	204,791	302	+237	0.45	305	125	14
May 2015	63,573	94	+104	0.45	305	135	17

TABLE [illegible] (continued)

Ineos Historical Fall-Off Testing Results WDW-163, WDW-164, WDW-165

WDW-165

Date of Test	Transmissibility (mD-ft/cP)	Permeability (mD)	Skin Factor	Viscosity (cP)	Thickness (feet)	Injection Rate (gpm)	Fall-off Period (hr)
Nov 1985	38,546	52	+29	0.63	467	--	--
Oct 1986	89,694	121	+123	0.63	467	--	--
August 1987	98,589	133	+125	0.63	467	--	--
Oct 1988	69,679	94	+109	0.63	467	--	--
April 1989	103,778	140	+101	0.63	467	--	--
May 1990	40,770	55	+93	0.63	467	--	--
May 1991	56,337	76	+71	0.63	467	--	--
Feb 1992	85,987	116	+69	0.63	467	--	--
April 1993	27,872	38	+24	0.63	467	100	13
March 1994	81,294	110	+44	0.63	467	100	12
March 1995	39,214	40	+43	0.47	467	100	13
March 1996	60,174	61	+56	0.47	467	115	11
March 1997	36,085	36	+25	0.47	467	150	12
April 1998	53,938	54	+22	0.47	467	290	11
April 1999	41,500	42	+40	0.47	467	160	12
April 2000	101,032	102	+62	0.47	467	190	15
March 2001	97,131	98	+66	0.47	467	260	17
March 2002	96,790	97	+49	0.47	467	305	14
March 2003	69,628	70	+50	0.47	467	241	14
April 2004	53,457	54	+53	0.47	467	150	17
March 2005	44,208	44	+47	0.47	467	150	14
April 2006	88,890	90	+43	0.47	467	325	14
May 2007	85,580	86	+30	0.47	467	360	15
April 2008	62,229	63	+57	0.47	467	172	20
April 2009	74,879	75	+57	0.47	467	220	12
March 2010	72,728	73	+44	0.47	467	180	12
April 2011	78,848	79	+36	0.47	467	280	14
July 2012	83,228	84	+38	0.47	467	310	20
April 2013	59,521	60	+79	0.47	467	90	13
May 2014	57,539	58	+65	0.47	467	155	14
August 2015	97,261	98	+124	0.47	467	95	19

TERRA DYNAMICS INC

Table 7-4
Historical Injected Volumes

Ineos USA LLC
Green Lake Plant
Port Lavaca, Texas

MAY - 6 2009

Year	WDW-163	WDW-164	WDW-165
1981	--	--	2.568
1982	--	63.118	51.507
1983	--	61.109	68.774
1984	36.391	56.811	63.195
1985	45.276	62.415	63.412
1986	54.282	57.083	57.795
1987	65.155	58.190	48.669
1988	52.621	60.168	63.271
1989	35.264	56.340	59.363
1990	28.150	77.747	78.798
1991	129.920	26.393	14.159
1992	82.431	39.015	52.052
1993	60.127	67.232	23.763
1994	66.393	62.959	61.770
1995	65.418	58.811	72.945
1996	54.409	64.866	64.888
1997	72.423	85.467	88.785
1998	68.792	75.870	76.551
1999	72.062	79.268	80.242
2000	74.649	90.692	88.546
2001	72.815	83.295	83.369
2002	75.796	89.458	84.348
2003	70.283	76.273	73.634
2004	74.954	80.840	83.492
2005	75.678	60.626	97.144
2006	69.312	65.838	107.763
2007	75.157	85.621	86.168

NOTE: Volumes are reported in million gallons, rounded up to the next 1,000-gallon increment

Table 7-5a
(2016 addendum)

Flowing and Static Bottom-hole Pressure Data

WDW-163 Injection Interval

Date of Test	4/15/09	4/2/10	4/27/11	7/15/12	4/30/13	5/13/14	7/22/15
Measured Static Pressure (psia)	2,152	2,152	2,052	2,149	2,146	2,136	2,138
Shut In Length (hrs)	19	21	21	21	21	21	25
Gauge Depth[1] (KB)	5,400	5,400	5,400	5,400	5,400	5,400	5,400
Fluid Gradient (psi/ft)	0.452	0.451	0.451	0.451	0.451	0.451	0.451
Static Pressure at Reference Depth[2] (psia)	2,180	2,181	2,081	2,178	2,175	2,165	2,167
Injection Rate (gpm)	90	150	105	110	150	125	170
Final Flowing Pressure (psia)	2,667	2,526	2,433	2,590	2,698	2,463	2,402
Flowing Pressure at Reference Depth[2] (psia)	2,748	2,555	2,462	2,619	2,727	2,492	2,431
Skin Factor	+1,291	+276	+6	+477	+360	+189	+357
Skin Pressure Drop (psi)	511	362	170	433	538	312	257
Flowing Press. (psia) at Ref. Depth [2] w/Skin Correction	2,237	2,191	2,292	2,186	2,189	2,180	2,174
Thickness (ft)	244	244	244	244	244	244	244
Viscosity (cP)	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Transmissibility (mD-ft/cP)	1,108,334	552,370	19,078	585,916	485,308	366,297	470,537
Permeability (mD)	2,348	1,177	41	1,249	1,034	781	1,003

Notes: Reference depth is 5,464 feet KB, at approximate middle of Injection Interval Sand 3; original static BHP at this depth was 2,190 psi

Table 7-5a (continued)
(2016 addendum)

Flowing and Static Bottom-hole Pressure Data

WDW-164 Injection Interval

Date of Test	4/16/09	3/30/10	4/28/11	7/13/12	5/2/13	5/14/14	5/27/15
Measured Static Pressure (psia)	3,014	3,021	3,012	3,026	3,012	2,991	3,003
Shut In Length (hrs)	12	15	13	14	14	14	17
Gauge Depth[1] (KB)	7,475	7,475	7,475	7,475	7,470	7,440	7,475
Fluid Gradient (psi/ft)	0.451	0.451	0.451	0.451	0.451	0.451	0.451
Static Pressure at Reference Depth[2] (psia)	3,077	3,084	3,075	3,089	3,077	3,069	3,066
Injection Rate (gpm)	280	200	300	370	250	125	135
Final Flowing Pressure (psia)	3,638	3,427	3,581	3,691	3,673	3,720	4,165
Flowing Pressure at Reference Depth[2] (psia)	4,370	3,490	3,644	3,754	3,738	3,798	4,228
Skin Factor	+50	+39	+37	+43	+60	+237	+104
Skin Pressure Drop (psi)	530	324	460	552	577	701	1,072
Flowing Press. (psia) at Ref. Depth[2] w/Skin Correction	3,171	3,166	3,184	3,202	3,161	3,097	3,156
Thickness (ft)	305	305	305	305	305	305	305
Viscosity (cP)	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Transmissibility (mD-ft/cP)	128,427	115,427	116,356	140,250	126,867	204,791	63,573
Permeability (mD)	189	170	172	207	187	302	94

Notes: Reference depth is 7,614 feet KB, near top of Injection Interval; original static BHP at this depth was 3,175 psi

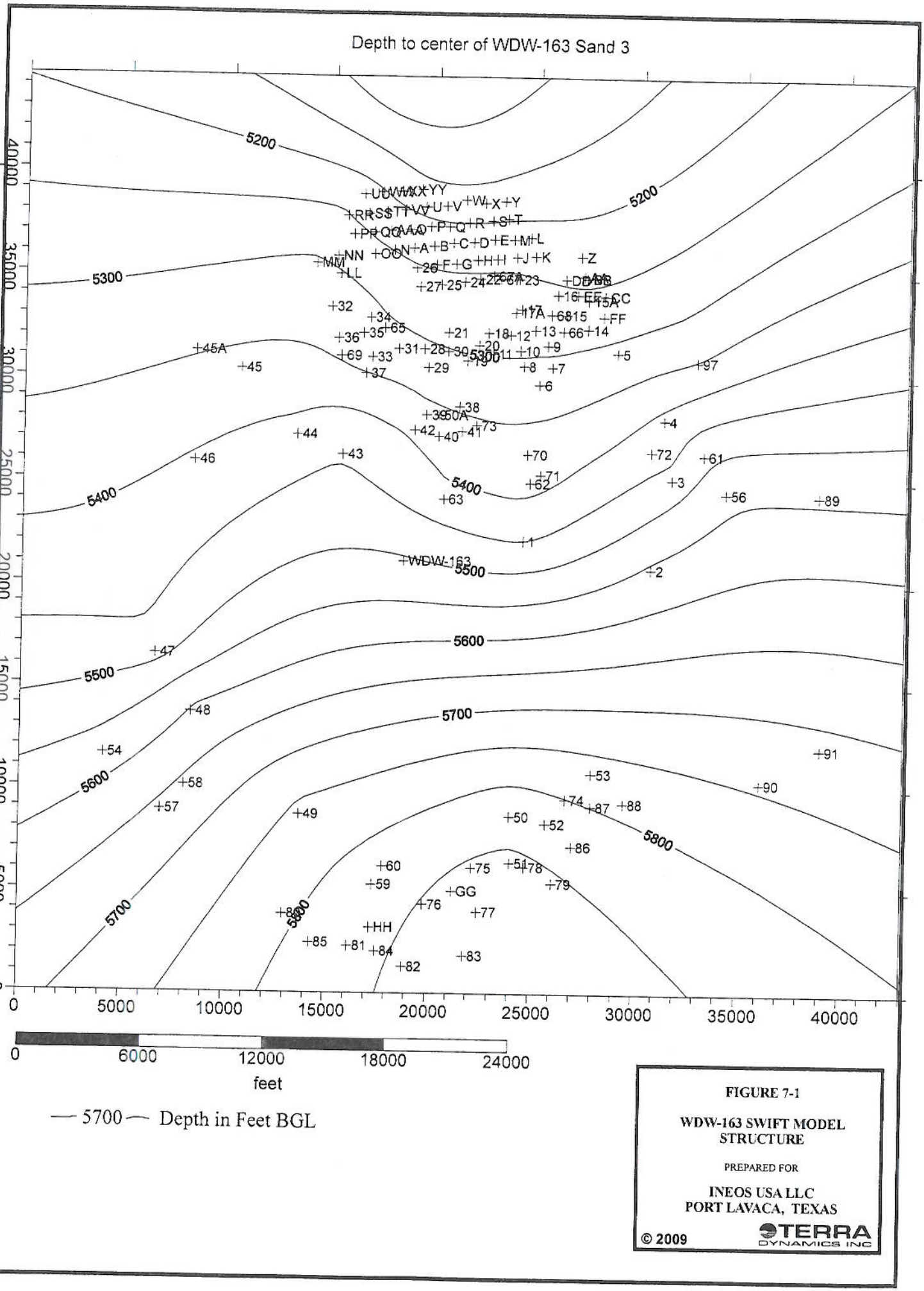
Table 7-5a (continued)
(2016 addendum)

Flowing and Static Bottom-hole Pressure Data

WDW-165 Injection Interval

Date of Test	4/18/09	3/31/10	4/29/11	7/11/12	5/1/13	5/15/14	8/27/15
Measured Static Pressure (psia)	2,714	2,742	2,725	2,736	2,730	2,716	2,711
Shut In Length (hrs)	12	12	14	20	13	14	19
Gauge Depth[1] (KB)	6,770	6,770	6,770	6,770	6,800	6,800	6,800
Fluid Gradient (psi/ft)	0.451	0.451	0.451	0.451	0.451	0.451	0.451
Static Pressure at Reference Depth (psia)	2,800	2,828	2,811	2,822	2,802	2,788	2,783
Injection Rate (gpm)	220	180	280	310	90	155	95
Final Flowing Pressure (psia)	3,660	3,370	3,480	3,580	3,368	3,671	3,337
Flowing Pressure at Reference Depth (psia)	3,746	3,456	3,566	3,666	3,440	3,743	3,409
Skin Factor	+57	+44	+36	+38	+79	+65	+124
Skin Pressure Drop (psi)	816	529	611	690	577	847	586
Flowing Press. (psia) at Ref. Depth w/Skin Correction	2,930	2,927	2,955	2,976	2,863	2,896	2,823
Thickness (ft)	467	467	467	467	467	467	467
Viscosity (cP)	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Transmissibility (mD-ft/cP)	74,879	72,728	78,848	83,228	59,521	57,539	97,261
Permeability (mD)	75	73	79	84	60	58	98

Notes: Reference depth is 6,960 feet KB, at approximate top of Injection Interval; original static BHP at this depth was 2,881 psi



Drawing No.: FIG 7-1
Date: 2-12-09
Job No.: 08-160

Drawn By: PRG
Designed By: PRG
Checked By: TM

FIGURE 7-1

WDW-163 SWIFT MODEL STRUCTURE

PREPARED FOR

INEOS USA LLC
PORT LAVACA, TEXAS

TERRA DYNAMICS INC